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THE DISTRIBUTION OF INTERPLANETARY HYDROGEN

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by

T. N. L. Patterson, F. S. Johnson, and W. B. Hanson

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Southwest Center for Advanced Studies
P.O. Box 8478
Dallas 5, Texas

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ABSTRACT - A calculation is presented of the distribution of the neutral hydrogen in interplanetary space. The presence there of atomic hydrogen is indicated by some recent rocket-borne measurements of Morton and Purcell; their measurements showed that 15% of the observed scattered Lyman-α radiation was at a wavelength removed by more than 0.04Å from the line center. This component must be scattered by interplanetary hydrogen since telluric hydrogen cannot be expected to contribute significantly to so wide a profile.

The work described here is an extension of a recent theory of Axford, Dessler, and Gottlieb on the termination of the solar wind. These authors have proposed that a shock front is formed in the region where the momentum flux of solar protons just equals the pressure exerted by the galactic magnetic field. Beyond the shock front the solar protons velocities become randomized but remain approximately equal to the solar wind velocity. These energetic protons in time undergo charge exchange with the neutral galactic hydrogen creating an isotropic source of high energy neutral hydrogen atoms, some of which move in the general direction of the Sun.

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The distribution of neutral hydrogen around the Sun, resulting from this flux of neutral hydrogen atoms, is calculated taking account of their loss by photo-ionization and charge exchange on their path towards the Sun. The absolute concentration of hydrogen from this source is derived using the results of Morton and Purcell. Following this procedure it is found that when the solar wind velocity and concentration at 1 A.U. are respectively 400 km sec^{-1} and 5 cm^{-3}, the concentration of interplanetary neutral hydrogen in the vicinity of Earth is about 0.02 cm^{-3} with the shock front located at about 20 A.U. from the Sun.

Brief consideration is given to the dynamics of the shock front transition region and a tentative estimate is made of the galactic magnetic field strength. A value of about 3γ is obtained.

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I. Introduction

It is possible to develop a rather complete picture of the distribution of neutral and ionized hydrogen throughout the solar system. This has already been done by Axford et al[1] for ionized hydrogen. However, a very discriminating observation by Morton and Purcell[2] makes it possible to narrow the range of uncertainty in the picture presented by Axford et al, and further it makes it possible to place rather stringent conditions on the concentrations of neutral hydrogen in the solar system.

The picture of the solar wind presented by Axford et al is that it blows more or less symmetrically and continuously outward from the sun with a nearly constant, highly supersonic velocity. Hence, the particle concentrations in the solar wind, and the momentum flux directed radially from the sun, decrease according to the inverse square of the distance from the sun. At that distance (∿ 10-50 A.U.) where the momentum flux just equals the galactic pressure (primarily that of the galactic magnetic field), the solar wind passes through a standing shock front, beyond which it is subsonic. In the region beyond the shock front, the solar wind protons have a nearly isotropic velocity distribution, but the individual particle velocities remain about equal to those in the solar wind. In time, the energetic protons undergo charge exchange with neutral galactic hydrogen. This process leaves low energy protons in the transition region beyond the shock front, and provides an isotropic source of high energy neutral hydrogen atoms. Some of these move through the shock front and in the general direction of the sun. Taking into account their velocity, the ionizing solar radiation, and the likelihood of charge exchange with the solar wind, the distribution of the neutral hydrogen atoms in interplanetary space is calculated in this paper.

Morton's and Purcell's observations were made with a radiation detector sensitive in the Lyman-α region of the spectrum. An atomic hydrogen filter, which could be turned off and on, was placed in front of the detector--the filter, when on, virtually removed all response within a bandwidth of 0.08 A centered on the Lyman-α line. The device was used in a rocket flown at night into the ionospheric E region. With the filter off, observations were made similar to those of Kupperian et al[(3)]; these earlier observations have been interpreted as indicating a telluric hydrogen corona which scatters solar Lyman-α radiation[(4)], although some quantitative difficulties exist with this interpretation[(5)]. When Morton's and Purcell's filter was turned on, the response when looking in an upward direction dropped to 15% of the response with the filter off. Thus 85% of the response with the filter off was due to radiation within 0.04 A of the center of the Lyman-α line; this contribution should be almost entirely due to radiation scattered in the telluric hydrogen corona, following the arguments of Johnson and Fish[4]. However, the 15% of the response due to radiation with wavelengths greater than 0.04 A from the line center cannot have been due to scattering in the telluric corona; it must have come from space. The only tenable source appears to be the scattering of solar Lyman-α radiation by interplanetary hydrogen[6], for which Doppler shifts would be expected to shift the radiation largely outside the pass band of the filter.

If the interplanetary hydrogen were cold and moving systematically (for example, in orbit around the sun with orbits similar to Mars or Jupiter), Doppler shifts would be expected which would vary with the viewing direction, and these should have caused variations to appear in the observed intensity depending upon the direction of viewing. Within the limits of observational accuracy, Morton and Purcell saw no variation of this sort, and this indicates that the interplanetary hydrogen has randomly oriented velocities which are large compared to the earth's orbital velocity. This means that the interplanetary hydrogen must be hotter than about 10^5 °K.

Owing to the effectiveness of solar ionizing radiation in ionizing interplanetary hydrogen, or of solar-wind charge exchange in driving it out of interplanetary space, one can maintain significant concentrations of interplanetary hydrogen only by continually renewing it. Further, calculations to be presented later in this paper indicate that the interplanetary hydrogen atoms must have high velocities ($\sim$ 300 km/sec) if they are to approach the sun closely enough to contribute to the observed distribution of scattered Lyman-α radiation. Thus, the picture presented by Axford et al describes a source of the very type needed to explain the observations of Morton and Purcell. Conversely, Morton's and Purcell's observations provide a striking confirmation of the essential accuracy of the picture presented by Axford et al.

2. The Hydrogen Distribution

It is assumed that a flux of neutral hydrogen is emitted isotropically from the surface of the shock front towards the sun and that the particles trace collisionless gravitational orbits about the Sun. The particles are lost by the processes of photo-ionization and charge exchange with solar-wind protons, according to

$$H + h\nu \rightarrow H^{+} + e \qquad (1)$$

and

$$H + H^{+} \rightarrow H^{+} + H \qquad (2)$$

The photo-ionization and charge-exchange loss rates may be written

$$\left(\frac{dN}{dt}\right)_{p.i.} = - \alpha N/r^2, \quad \left(\frac{dN}{dt}\right)_{c.e.} = - \gamma N/r^2, \qquad (3)$$

where N is the concentration of hydrogen atoms at distance r from the sun and α and γ are the loss parameters associated with ionization and charge exchange respectively. Thus the rate at which particles are destroyed inside a sphere of radius r is given by

$$\int_{\delta}^{r} 4\pi r^2 N(r)\ \left(\frac{\alpha + \gamma r}{r^2}\right)\ dr = 4\pi(\alpha + \gamma) \int_{\delta}^{r} N dr \qquad (4)$$

where δ is a radius defining the region inside of which collisions become important; its exact value is not important, since N(r) becomes very small close to the sun ($\sim$ 0.1 A.U.).

The expression for N(r) will be derived under the conservation principle that the total number of particles destroyed within the sphere of radius r as given by (4) must equal the net flux of neutral hydrogen into the sphere.

2.1 The Net Flux of Particles

Figure 1 shows the co-ordinate system used. The particle orbits are defined by the radial distance r and the angle ξ measured from the line joining the center to the source of the particles at dS. Particles leaving dS in a small solid angle in the direction θ follow the path shown, intersecting the sphere of radius r at co-ordinate points (r,ξ_1) and (r,ξ_2). The particles undergo loss processes (1) and (2) during transit from dS to ξ_1 and from ξ_1 to ξ_2. For any solid angle the number of particles per second entering the sphere at ξ_1 less the number leaving the sphere at ξ_2 gives a loss rate which may then be integrated over the entire allowable solid angle.

Let F_o be the number of particles per second emitted from the shock front along a particular trajectory, and let F be the number flowing per second at any point along the orbit. If the distance along the orbit is denoted by s, then the effective number of particles in ds is given by F ds/v, where ds/v is the time spent in transit across ds and v is the local velocity. According to (3), the number decaying per second is

$$dF = - F \frac{(\alpha + \gamma)}{r^2} \frac{ds}{v} \tag{5}$$

The flow at any point s along the orbit may therefore be written

$$F = F_o \exp \left[- \int_o^s \frac{\alpha + \gamma}{vr^2} ds\right]. \tag{6}$$

In the co-ordinate system (r,ξ),

$$\int_o^s \frac{\alpha + \gamma}{vr^2} ds = \int_o^\xi \frac{\alpha + \gamma}{vr^2} \frac{ds}{d\xi} d\xi. \tag{7}$$

Now $ds/d\xi = \dot{s}/\dot{\xi} = v/\dot{\xi}$. Conservation of angular momentum gives

$$r^2\dot{\xi} = v_o r_o \sin \theta = h = \text{constant}, \tag{8}$$

where v_o is the initial velocity and r_o is the distance from the sun to the shock front. Hence,

$$\dot{\xi} = h/r^2. \tag{9}$$

Substituting into (7) gives

$$\int_o^s \frac{(\alpha + \gamma)}{vr^2} ds = \int_o^\xi \frac{(\alpha + \gamma)}{h} d\xi = (\alpha + \gamma)\ \xi/h. \tag{10}$$

Thus (6) reduces to

$$F = F_o \exp [- (\alpha + \gamma)\ \xi/h]. \tag{11}$$

This equation breaks down for the case $\theta = 0$ which is considered later.

The number of particles leaving dS per cm^2-sec in the solid angle $d\omega$ is $(\phi\, d\omega/\pi) \cos\theta$, where ϕ is the total flux of fast hydrogen atoms per cm^2-sec flowing out of the shock front on the side facing the sun. The magnitude of ϕ is equal to half of the solar-wind flux into the shock front under steady-state conditions (assuming that the charge exchange occurs very close to the shock front). The net flow into the sphere of radius r using (11) is therefore

$$\phi \frac{d\omega}{\pi} \cos\theta \{ \exp[-(\alpha+\gamma)\xi_1/h] - \exp[-(\alpha+\gamma)\xi_2/h]\}.$$

Since there is symmetry about the axis from the sun to dS, and since all areas dS contribute equally, the net flow into the sphere of radius r is

$$\Gamma(r) = 4\phi\pi r_o^2 \int_{\theta_o}^{\theta_1} \sin 2\theta \{ \exp[-(\alpha+\gamma)\xi_1/h] - \exp[-(\alpha+\gamma)\xi_2/h]\}\, d\theta, \quad (12)$$

where h, ξ_1, and ξ_2 are functions of θ. The expressions for the limits of integration and ξ_1 and ξ_2 are derived later.

The lower limit θ_o is introduced to avoid the singularity which occurs as $\theta \to 0$ in the numerical evaluation of the integral. This is equivalent to saying that particles described by (12) do not travel closer than a distance δ to the sun. Also implied in the definition of δ is that particles travelling closer to the sun than δ are removed by effective collisions with the sun and so only contribute to the ionization on their inward path.

2.2 The Orbital Equation

The motion of the particles is described by

$$\frac{d^2u}{d\xi^2} + u = \beta/h^2, \tag{13}$$

where β = GM, u = 1/r, G is the gravitational constant, M is the solar mass, and h is the angular momentum per unit mass defined by (8). The solution of (13) with the appropriate boundary conditions is

$$u = A + B \sin \xi + C \cos \xi, \tag{14}$$

where $$A = \beta/h^2;\ B = (v_o \cos \theta)/h;\ C = 1/r_o - \beta/h^2. \tag{15}$$

The upper limit to θ may be derived by noting that, at this angle of projection, the trajectory of the particle is tangential to the sphere of radius r so that by conservation of angular momentum,

$$\sin \theta_1 = vr/v_o r_o.$$

The velocity is given by

$$v = [v_o{}^2 + 2\beta(1/r - 1/r_o)]^{1/2} \tag{16}$$

Hence,

$$\sin \theta_1 = [v_o{}^2 + 2\beta(1/r - 1/r_o)]^{1/2}\ r/v_o r_o. \tag{17}$$

Similarly θ_o may be derived by noting that at this angle of projection particles will pass tangential to the sphere of radius δ, so that

$$\sin\theta_o = [v_o^2 + 2\beta(1/\delta - 1/r_o)]^{1/2}\ \delta/v_o r_o. \tag{18}$$

The roots of (14) for a given r give ξ_1 and ξ_2, and the result is

$$\sin\xi_{1,2} = \frac{B(1/r - A) \mp C[B^2 + C^2 - (1/r - A)^2]^{1/2}}{(B^2 + C^2)}, \tag{19}$$

where the negative sign refers to ξ_1 and the positive sign to ξ_2.

Since (14) has been squared to derive this result, a problem arises here as regards choosing the correct quadrants of ξ_1 and ξ_2. In practice this is resolved by restricting the choice to two quadrants from inspection of the sign of (19) together with substitution back into (14).

2.3 Complete solution:

Equating the total number of particles destroyed per second in the sphere to the net flow into the sphere gives

$$4\pi(\alpha + \gamma)\int_\delta^r N\,dr = \Gamma(r),$$

using (4) and (12). Differentiating with respect to r gives

$$N(r) = \frac{\partial\Gamma}{\partial r}/[4\pi(\alpha + \gamma)] \tag{20}$$

$$= \frac{\partial G_1}{\partial r},$$

where

$$G_1(r) = \Gamma(r)/[4\pi(\alpha + \gamma)]. \tag{21}$$

The contribution to (12) from angles less than θ_o is derived by assuming radial orbits and by noting that all particles impinging on the sphere of radius δ are effectively lost. Thus using (16),

$$\int_o^s \frac{\alpha + \gamma}{vr^2}\, ds = \int_r^{r_o} \frac{\alpha + \gamma}{vr^2}\, dr = (\alpha + \gamma)\ (v - v_o)/\beta,$$

where $s = r_o - r$ for radial orbits. The total flux with angles less than θ_o is therefore

$$4\pi r_o{}^2 \phi \int_o^{\theta_o} \sin 2\theta \exp\left[-\ (\alpha + \gamma)\ (v - v_o)/\beta\right] d\theta.$$

Differentiating this expression to obtain the contribution to N finally gives

$$N = \frac{\partial G_1}{\partial r} + G_2(r), \tag{22}$$

where using (16),

$$G_2(r) = \frac{\phi r_\delta{}^2}{2r^2 v}\ (1 - \cos 2\theta) \exp\left[-\ (\alpha + \gamma)\ (v - v_o)/\beta\right]. \tag{23}$$

With the value chosen for δ (0.1 A.U.), G_2 may be neglected.

2.4 Contribution from charge-exchange

Particles which charge exchange with the solar-wind protons are not actually lost from the hydrogen distribution as is the case when photo-ionization occurs. Instead, the particles which charge-exchange constitute an additional hydrogen component which travels radially outward at the solar wind velocity. Subsequent losses to this radial component by photo-ionization are small and are neglected in the evaluation of this component.

Neglecting the hydrogen atoms after charge exchange, the "loss" from charge exchange alone inside the sphere of radius r is,

$$\left(\frac{\gamma}{\alpha + \gamma}\right) \Gamma(r). \tag{24}$$

The contribution from the angles less than θ_o is derived as before and is

$$\frac{\gamma}{\alpha + \gamma} 2\pi r_o^2 \phi (1 - \cos 2\theta_o) \exp [- (\alpha + \gamma) (v - v_o)/\beta] \tag{25}$$

The sum of (24) and (25) must equal the outward flow per second of hydrogen atoms which have undergone charge exchange; this is

$$4\pi r^2 V N',$$

where N' is the contribution to the hydrogen concentration due to charge-exchanged hydrogen, and V is the solar wind velocity. Thus

$$N' = H_1(r) + H_2(r) \tag{26}$$

where

$$H_1(r) = \frac{\gamma}{\alpha + \gamma} \Gamma(r)/4\pi r^2 V, \tag{27}$$

and

$$H_2(r) = \frac{\gamma}{\alpha + \gamma} \frac{\phi r_o^2}{2r^2 V} (1 - \cos 2\theta_o) \exp [- (\alpha + \gamma) (v - v_o)/\beta]. \tag{28}$$

H_1 and H_2 are related to G_1 and G_2 by

$$H_1(r) = \gamma G_1(r)/r^2 V \tag{29}$$

and

$$H_2(r) = \frac{\gamma}{\alpha + \gamma} \, vG_2(r)/V \tag{30}$$

The contribution from N' is found to be small but significant.

3. Calculations

In order to solve for the interplanetary hydrogen distribution, certain of the parameters in (12) must be specified. A value for α of 10^{20} cm^2 sec^{-1} was adopted on the basis of Hinteregger's data[7] taken outside the Earth's atmosphere. If the solar wind protons concentration is expressed as $n = K/r^2$, then the value of γ is given by $K\sigma V$, where α is the charge exchange cross-section and V is the solar wind velocity. In the velocity range of interest, the product σV is nearly constant with a magnitude of about 10^{-7} cm^3 sec^{-1}. The values of σ given by Dalgarno[8] were used to obtain the values of γ presented in Table I.

The integral in (12) was evaluated numerically for several values of the solar wind velocity and for different values of r_o, the distance to the shock front. The values chosen for v_o are discussed later. The solar wind parameters were chosen such that $n(r_e)V^2 = 8 \times 10^{15}$ cm^{-1} sec^{-2} where $n(r_e)$ refers to the proton concentration at 1 A.U.[9] Table 1 shows the resultant values of γ and $n(r_e)$ for three different solar wind velocities. The form of the interplanetary hydrogen distribution is shown in Figure 2 by the curve labelled hot component, taking $n(r_e) = 5$ protons/cm^3,

$V = 400$ km/sec, and $r_o = 50$ A.U. The shape of the curve depends principally on V and is quite insensitive to the value of r_o chosen, but, as is shown later, r_o is important in normalizing the curve, i.e., in determining the value of ϕ in (12). The crosses indicate the distribution excluding the contribution due to N' as given by (26).

4. Normalization of the Interplanetary Hydrogen Distribution

Only the relative distribution of interplanetary hydrogen has been established by the preceding calculations. The normalization of this curve is accomplished by determining how much hydrogen distributed in this manner is required to explain the observed intensities of scattered Lyman-α.

The intensity of scattered solar Lyman-α radiation as seen from Earth when viewing in the antisolar direction is given by:

$$\mathcal{J} = \frac{1}{4\pi} \int_{-\infty}^{\infty} \int_{r_e}^{R} F_\nu \left(\frac{r_e}{r}\right)^2 k_\nu \, d\nu \, dr \text{ ergs cm}^{-2} \text{ sec}^{-1} \text{ sterad}^{-1} \qquad (31)$$

where $F_\nu \, d\nu$ is the flux at 1 A.U. of Lyman-α radiation from the Sun in the frequency interval $(\nu, \nu + d\nu)$, r_e is the astronomical unit, k_ν is the absorption coefficient and R is the extent of the hydrogen cloud. Adopting a value of 6 ergs cm^{-2} sec^{-1} at r_e distributed over a Gaussian profile for the solar Lyman-α flux, and substituting for the absorption coefficient as given by Mitchell and Zemansky[10], gives

$$\mathcal{J} = \frac{4.95 \times 10^{-3}}{[(\Delta\nu_I)^2 + (\Delta\nu_S)^2]^{1/2}} \, r_e^2 \int_{r_e}^{R} N(r) \, dr/r^2 \qquad (32)$$

is also shown in Figure 2. This curve was normalized by assuming that all of the interplanetary scattering arises from the cool hydrogen. One can compare the distributions of hot and cool hydrogen that would be required to explain the intensity of the interplanetary glow. Some combination of the two must, in fact, make up the interplanetary source.

The main contribution to scattered Lyman-α radiation from the cooler source occurs near 2 A.U. At this distance from the sun, there must be a considerable mean streaming motion toward the sun. The individual particle velocities will be slightly in excess of the earth's orbital velocity, and roughly isotropic over the hemisphere facing the sun, but markedly deficient in velocity vectors away from the sun. Looking in the antisolar direction, the scattered radiation should be Doppler shifted towards shorter wavelengths, due to the mean streaming velocity of the scattering medium towards the earth. Towards the horizon in the direction of the earth's orbital motion, a greater doppler shift to shorter wavelengths must be expected, something in excess of that to be expected from the Earth's orbital velocity alone ($\sim$ 0.12 A). Toward the opposite horizon, a shift to longer wavelengths is to be expected; somewhere between that horizon and the antisolar direction the Doppler shift must be zero. For the cooler hydrogen, a detector such as Morton's and Purcell's scanning through the antisolar direction in the plane of the ecliptic should expect to see a relatively uniform response from horizon to horizon, except for a gap somewhere to the west of the anti-solar direction (possibly near the horizon itself, depending upon the where $\Delta\nu_I$ and $\Delta\nu_S$ are the Doppler widths of the interplanetary and solar lines respectively.

Taking the Doppler width of the solar Lyman-α to be 1Å

$$\mathcal{J} = \frac{7.42 \times 10^{-2}}{[4.13 + (1.12 \times 10^{-2}\ v_0)^2]^{1/2}} \int_{r_e}^{R} N(r)dr/r^2 \text{ ergs cm}^{-2}\text{sec}^{-1}\text{sterad}^{-1} \quad (33)$$

where r and R are now expressed in A.U.

The observations of Kupperian, Byram, Chubb, and Friedman[11] give a nightglow Lyman-α intensity of 3.2×10^{-3} ergs. According to the observations of Morton and Purcell[2], only 15% of this flux passes their narrow-band hydrogen filter and hence would be due to scattering by the interplanetary hydrogen. By equating 4.8×10^{-4} ergs cm^{-2} sec^{-1} sterad^{-1} to $\mathcal{J}$ as given by (33), a normalization for N(r) is obtained, and this is shown in Figure 2. This normalization assumes that only hydrogen atoms which have attained nearly the solar wind velocity by charge exchange beyond the shock front contribute to the interplanetary scattering of Lyman-α radiation.

Some of the cool galactic hydrogen must also be expected to penetrate into interplanetary space, and the possibility exists that it also contributes to the source of interplanetary scattering of Lyman-α radiation. A calculated distribution of galactic hydrogen, assuming randomly directed velocities of 10 km/sec at the shock front (roughly, the velocity of the solar system through galactic hydrogen, randomized by collisions with slowed-down solar protons well beyond the shock front), time of observation).

Examination of Morton's and Purcell's data does not disclose any gap of the sort described above, and this indicates that the scattering contribution from cooler hydrogen is not very important. It is not easy to set any upper limit on what its contribution might be compared with the hotter hydrogen, as the total response is not very large. We might arbitrarily state that the contribution of the cooler hydrogen could not exceed that of the hotter without this fact having been apparent in the records. If the contributions were equal, the two curves shown in Figure 2 could each be reduced by a factor of two to provide a reasonable representation of the concentration of both hot and cool hydrogen in interplanetary space.

5. Determination of the position of the shock boundary and the galactic field strength

The concentration of cool hydrogen obtained for the outer portion of the solar system is surprisingly low. It is so low, in fact, that it has important consequences with regard to the thickness of the region behind the shock front--the cool hydrogen concentrations are so low that the removal of energy from protons beyond the shock front proceeds rather slowly, and the transition region must be rather thick.

If the transition region were thin, so that the source of hot hydrogen could be considered to be close to the shock front, then its concentration in interplanetary space would give an indication of the location of the shock front. If we assume that this charge exchange process takes place in a region Δr which is small compared to r_o, and that it gives rise to an iostropic emission of fast hydrogen atoms, then

$$\phi = \frac{1}{4}N(r_o)\ v_o = \frac{1}{2}(r_e/r_o)^2\ n(r_e)\ V \text{ atoms cm}^{-2}\text{ sec}^{-1} \tag{34}$$

where $N(r_o)$ is the interplanetary hydrogen concentration at r_o, and v_o is the random velocity of the protons in the compressed region just behind the shock front. Equation (34) states that half the solar wind flux into the shock region is returned to the solar cavity in the form of fast hydrogen atoms. The velocity v_o of the fast neutral hydrogen atoms emitted into the solar cavity by the charge exchange process is of the order of, but smaller than, the solar wind velocity. Since the details of the shock mechanism are only poorly understood, it has been assumed for the purposes of calculation that $v_o = 3V/4$. In any event, the subsequent determination of r_o, the distance to the shock front, is rather insensitive to the value of v_o. The value of r_o tends to decrease as v_o/V becomes smaller. Solving (34) for r_o, we obtain

$$r_o = r_e \left[\frac{8n(r_e)}{3N(r_o)} \right]^{1/2} \tag{35}$$

Table 2 shows the values of r_o for the different values $n(r_e)$ and V, using the corresponding value of $N(r_o)$ determined from the Lyman-α normalization process. Since the hot hydrogen atoms actually originate, on the average, a significant distance beyond the shockfront, the calculated values of r_o are too large; i.e., the shock front is probably somewhat closer to the sun than calculated.

Once the distance r_o has been determined, the magnitude of the galactic magnetic field can be calculated from the condition that the solar wind momentum flux at r_o must equal the galactic magnetic field energy density, i.e.,

$$B_g^2/8\pi = \rho V^2 (r_e/r_o)^2 \tag{36}$$

This relation is valid only if the total particle energy density in the galactic medium is small compared to the magnetic energy density. The values of B_g calculated from (36) corresponding to the different assumptions for the solar wind velocity are shown in Table 2. Again, because of failure to take into account the mean distance of origin of the hot hydrogen atoms beyond the shock front, the derived values of B_g are minimal values. The calculated galactic magnetic fields are rather larger in the vicinity of the solar system than generally supposed.

6. Discussion

The technique developed by Morton and Purcell for the observation of Lyman-α night glow can be very informative with regard to the distribution of atomic hydrogen in interplanetary space. About an order of magnitude greater sensitivity should be provided when the filter is turned on, and an attempt should be made to map the intensity contours across the sky, especially from the eastern to the western horizon. If two separate hydrogen components, hot and cool, are present in interplanetary space, the observations should give the relative concentrations.

The details of the energy loss by solar wind protons beyond the shock front cannot be said to be understood. In the treatment here, it has been assumed that the solar wind protons retain nearly all of their energy until a charge exchange takes place with cool galactic hydrogen--then the hydrogen atoms can be divided into two populations, cool and hot. If some sort of energy sharing process is active, so that after a solar wind proton loses its energy in a charge exchange reaction, it tends to increase its energy by energy exchange with the remaining protons, a complete spectrum of proton energies and of hydrogen atom energies must result. A further implicit assumption made here is that the protons behind the shock front do not share their energy with the electrons present. Observations such as those of Morton and Purcell probably cannot very accurately disclose the energy spectrum of the resultant hydrogen atoms in interplanetary space, but they should be capable of giving at least a rough indication.

The details of the energy loss by solar wind protons also affects the calculation of the distance to the shock front, and hence, the interplanetary field. This emphasizes the need to improve our understanding of the energy sharing processes beyond the shock front, as well as of the shock process itself.

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TABLE ONE

Solar Wind Concentrations and Charge Exchange Coefficients

V (km, sec^{-1})	$n(r_e)(cm^{-3})$	γ (cm^2 sec^{-1})
200	20	2.0×10^{20}
300	10	1.3×10^{20}
400	5	0.75×10^{20}

TABLE TWO

Distance to Shock Front and Galactic Magnetic Field Strength

V (km sec^{-1})	r_o (A.U.)	B (Gamma)
200	40	1.4
300	30	2.0
400	20	3.0

CAPTIONS

FIG. 1. THE COORDINATE SYSTEM

FIG. 2. CONCENTRATION OF NEUTRAL HYDROGEN AS A FUCTION OF DISTANCE FROM THE SUN REQUIRED TO ACCOUNT FOR THE LY-α OBSERVATIONS OF MORTON & PURCELL.

FIGURE 1

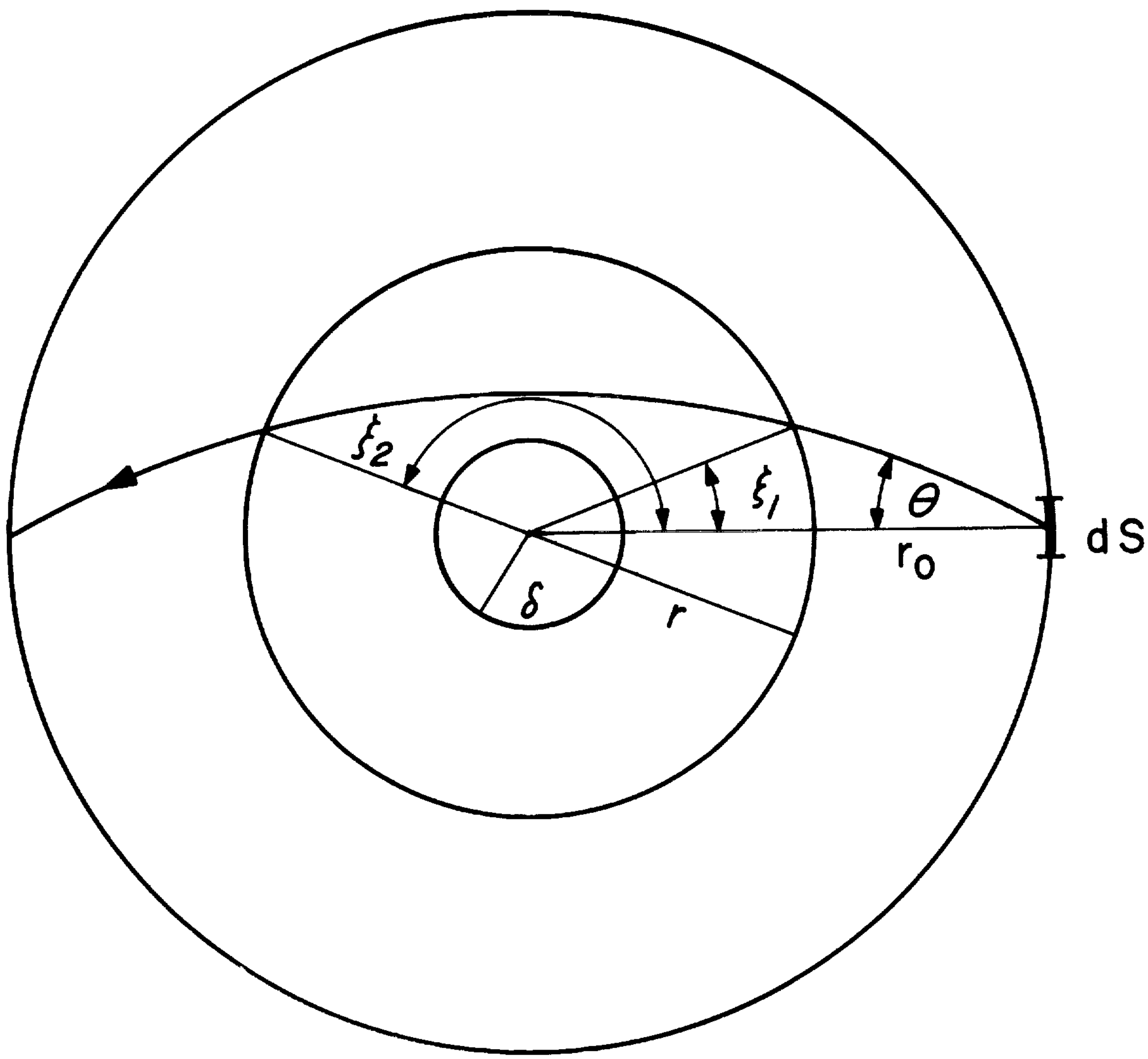
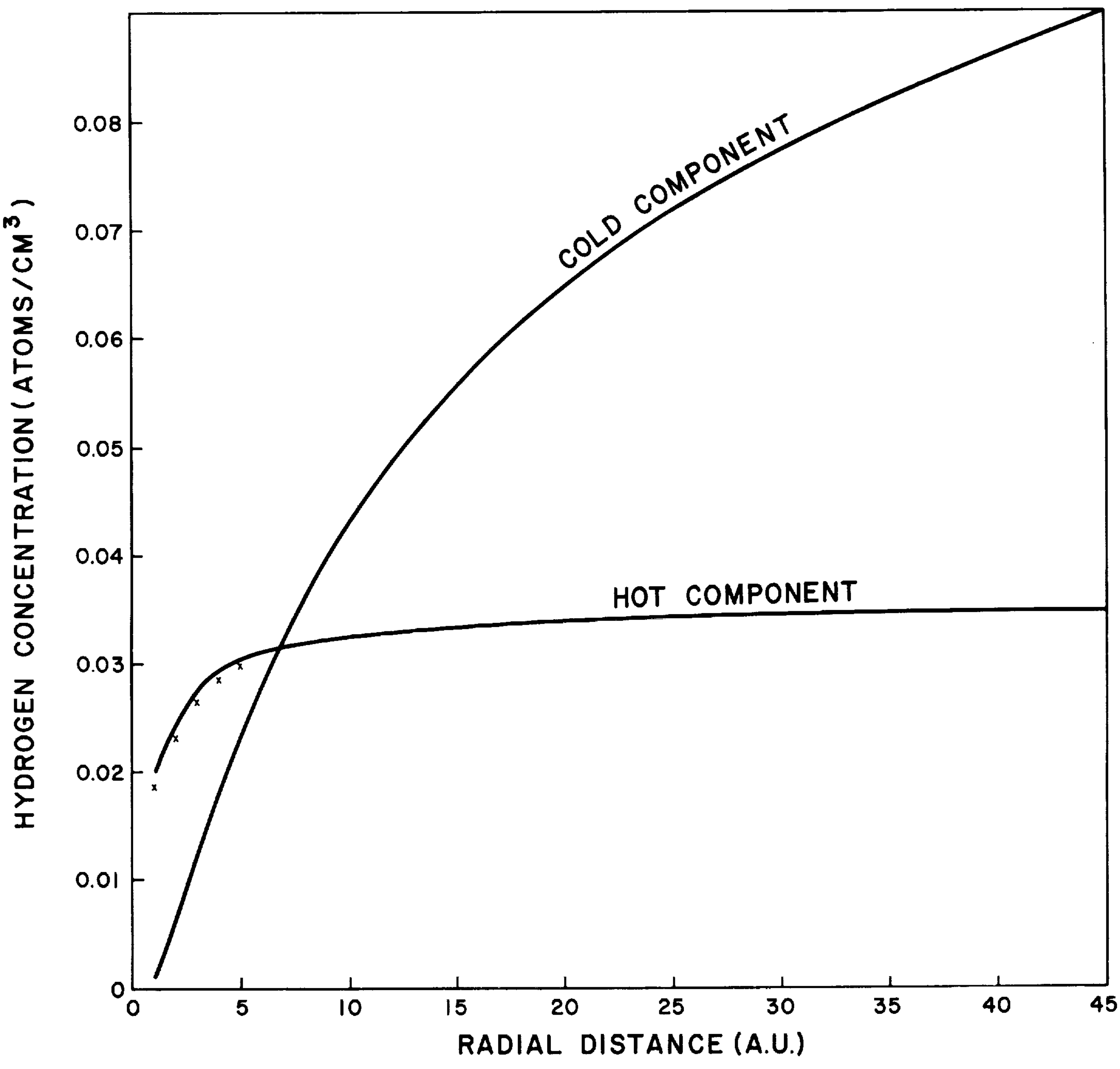


FIGURE 2


COLD COMPONENT
HOT COMPONENT
HYDROGEN CONCENTRATION (ATOMS/CM^3)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
5
10
15
20
25
30
35
40
45
RADIAL DISTANCE (A.U.)